Microwave heating experiment of lunar simulant (JSC-1A) using a bespoke industrial microwave apparatus

Conference or Workshop Item

MICROWAVE HEATING EXPERIMENT OF LUNAR SIMULANT (JSC-1A) USING A BESPOKE INDUSTRIAL MICROWAVE APPARATUS.

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Introduction: The Space Instrumentation Group at The Open University are investigating microwave sintering of lunar regolith/simulant as a potential fabrication method of 3D printing on the Moon to build lunar habitats. This has enabled us to integrate our existing expertise in 3D Concrete Printing [1, 2] and knowledge of lunar science and ISRU potential on the Moon [3] to perform a series of microwave sintering experiments aiming to develop a potential fabrication method of an extra-terrestrial construction process.

As part of this initiative, we have designed an industrial bespoke microwave heating apparatus. This apparatus will allow a thorough experimental investigation of the sintering mechanism of lunar regolith/simulant in the cavity. The mechanical properties of sintered specimens produced under optimal conditions can then be explored. The experiment will also be validated using COMSOL Multiphysics simulation software. In this contribution, we discuss the first outcomes using the bespoke microwave heating apparatus, and how COMSOL has been employed to understand the different characteristics of lunar regolith when subjected to microwave heating.

Microwave sintering: Microwave sintering of lunar regolith as a potential fabrication method of lunar habitat construction has become one of the favourite topics in recent years [4]. Previous research in this area, however, have been conducted using domestic microwaves, which are not ideal for sintering lunar simulants due to (i) incapable of withstand temperatures of up to 1,250 °C – the melting point of lunar regolith/simulant; (ii) not optimised to maximise microwave energy into a single hotspot; (iii) unable to mimic lunar atmospheric condition; (iv) it is not possible to measure sample surface temperature accurately; and (v) the fixed frequency at 2.45 GHz which is an optimal frequency to heat water molecules in food products but may not be optimal for inorganic solid materials such as lunar regolith.

Thus, an industrial bespoke microwave heating apparatus has been designed to overcome the current limitations. Figure 1 illustrates a design of the apparatus which includes two pyrometers, one viewfinder window, and a cylindrical cavity with a flange for a vacuum pump. The ports can also be connected to a mass spectrometer, permitting extraction and analysis of volatiles while specimens are heated. Volatiles in regolith can be extracted by heating the regolith between 300 and 900 °C [3, 5]. For example, a temperature of 700 °C is sufficient to obtain most of the H_2 and He [6]. Thus, the apparatus could also be used for measuring the types and amount of volatiles which could be used for propellant and life support (e.g. water). The new apparatus would allow to (i) maximise microwave energy in a single hotspot; (ii) measure the surface temperature and phase change of specimens under a near lunar atmospheric condition with more accuracy, and (iii) heating specimens of lunar simulant rapidly to be sintered/melted. This first version of the apparatus does not support multiple frequencies; however, this feature is planned to be added in a future upgrade.

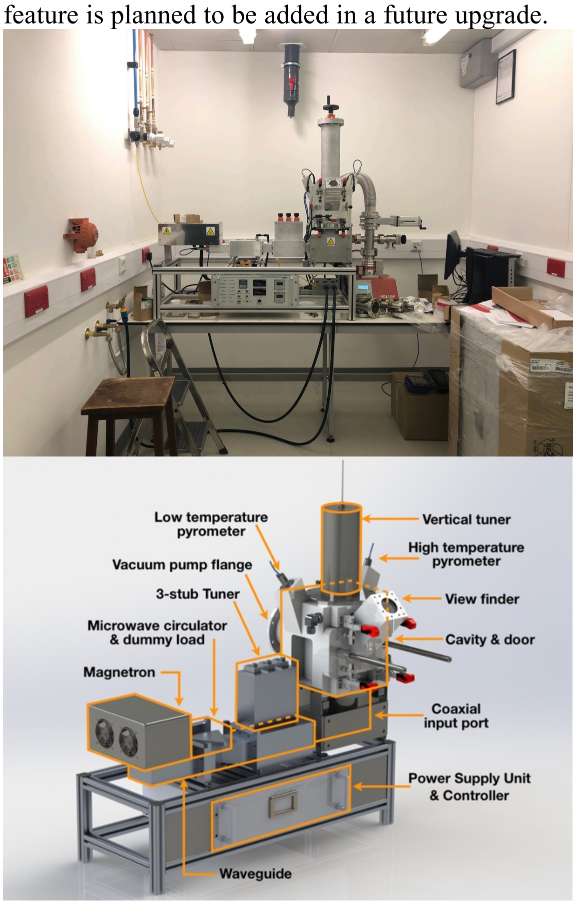

Figure 1: Bespoke microwave heating apparatus (above) and the detailed parts (bottom)

Numerical Modelling: As complementary research of the lab-experiment, we have chosen COMSOL (version 5.4), which has been used previously for a similar purpose [7]. COMSOL requires various parameters of material characteristics to simulate microwave heating phenomenon. The findings from the numerical modelling are (i) verifying the bespoke design of the cavity that could maximise microwave energy to heat specimens; (ii) understanding the sequence of sintering phenomenon by continual simulation of the surface and internal temperature of specimens; and (iii) identifying the different effects of sintering among frequencies in terms of the time and penetration depth.

Preliminary outcomes: A few preliminary experiments have been conducted, and the results show that 50 grams of lunar simulant JSC-1A, which has high iron contents, under 1,000 W of input power is well coupled with microwave energy and easily melted/sintered within 3 to 6 minutes. Figure 2 shows one of the sintered specimens with a partially melted core while the surface temperature of the specimen was 230 °C only. This is possibly caused by thermal runaway effect observed through the simulation of microwave heating behaviour of lunar regolith.

Figure 2: Microwave heated JSC-1A. Total 44 grams out of 50 grams was melted/sintered. Note that the white stuff on the surface of the sintered specimen is a residue of ceramic paper which prevents the specimen from being sintered to the crucible surface.

Besides, our early simulation experiments using the material properties of lunar regolith indicate that both highlands (TiO_2 0.5 wt%, FeO 6.2 wt%) and mare (TiO_2 8.5 wt%, FeO 16.6 wt%) regoliths were well coupled with microwave energy and reached beyond the melting point (initial melting temperature 1,373 K and completely molten temperature 1,653 K in this experiment) in 5 and 1.5 minutes respectively due to the thermal runaway effect. The pre-defined mass was 35 grams, and the input power was 1,000 W (see Figure 3). The simulation used total 63 sets of experiments with the combination of three materials (highlands, Mare High-Titanium, Mare Low-Titatinum), three masses (35, 19.5, 1 gram) and seven input powers (50, 100, 200, 400, 600, 800, 1,000 W). More data on the lab experiment and simulation would be given during the presentation.

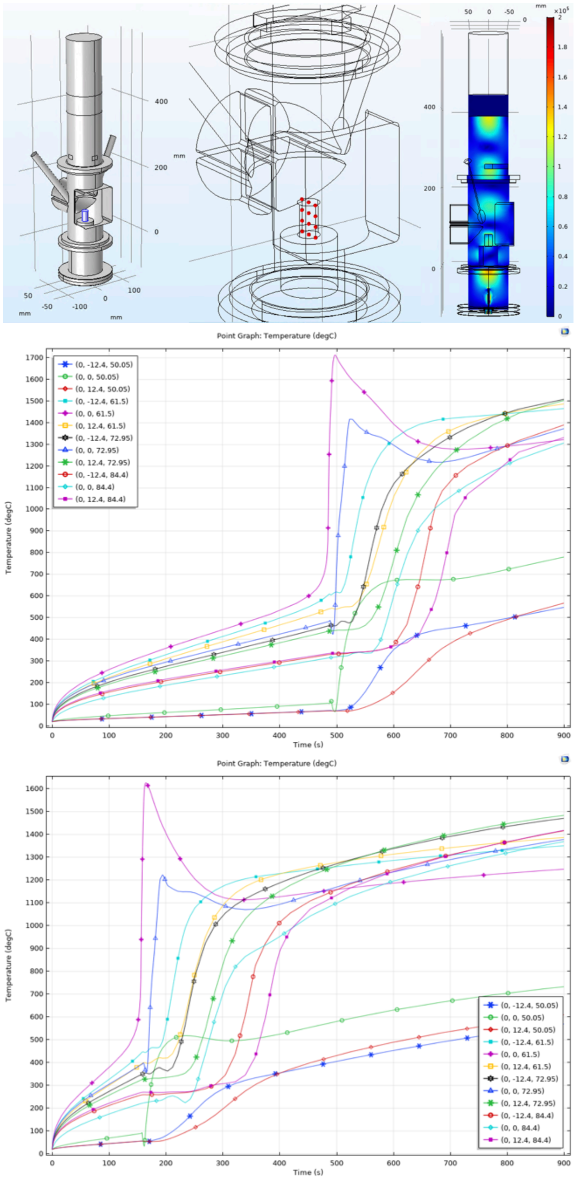

Figure 3: Simulation of the temperature curves of 12 sampled points in a specimen. Top – Simulation setting, Middle – Highlands regolith, Bottom – Mare regolith.

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